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$$\phi_{ij} = \frac{\sum_{s=1}^{N} \varepsilon_i(s)\cdot\varepsilon_j(s+1)}{\sqrt{\sum_{s=1}^{N} \varepsilon_i(s)^2}\cdot\sqrt{\sum_{s=1}^{N} \varepsilon_j(s+1)^2}} \quad \cdots\cdots\cdots \quad (3)$$

where i and j are item numbers attached to plant values, N is the number of samples of the residual used for calculation of the correlation function, and ϕ_{ij} is correlation function with respect to the item number j of the item number i, which represents auto-correlation function when $i=j$ and cross-correlation function when $i \neq j$.

By using the correlation function ϕ_{ij} obtained from the above-mentioned equation (3), whiteness qualification index AL_{ij} defined as the following equation (4) is obtained.

$$AL_{ij} = \frac{\sqrt{N-3}}{2} \log \frac{1+\phi_{ij}}{1-\phi_{ij}} \quad \cdots\cdots\cdots\cdots \quad (4)$$

Then, by making use of the characteristic that AL_{ij} depends upon the normal distribution N(0, 1) (having the average of 0 and the dispersion of 1), threshold level is determined in accordance with the erroneous diagnostic level.

There was conducted a qualification such that when the following equation (5) holds, correlation between the residuals ϵ_i and ϵ_j exists and this has not whiteness.

$|AL_{ij}| > ARL$ (5)

In accordance with the above-mentioned diagnostic system, typical abnormality or failure in the plants can be identified, but since information of time constant related to dynamic characteristic of the plant is not included in the above equation (3) for calculating the correlation function ϕ_{ij}, identification of abnormality or failure in consideration of time constant of the plant to be diagnosed such that influence of abnormality at a certain portion would be spreaded to another portion with a certain time delay could not be conducted.

SUMMARY OF THE INVENTION

It is an object of the present invention to further improve the plant diagnostic system previously proposed and to provide a plant diagnostic system having higher reliability which can conduct identification of abnormality or failure in consideration of time constant.

To achieve this object, the present invention is characterized by first means for determining, using the coefficient matrix of the auto regressive model, a time constant at which a change in the value of one plant variable has the graetest influence on the value of the plant variable and other plant variables; second means for calculating a time series of residual differences between an estimated value calculated by using said plant diagnostic model and an actual plant value obtained from said plant system so as to obtain the time series of residual differences; third means for qualifying whiteness of the time series of residual differences from said second means and the time constant from said first means so as to produce an index; fourth means for determining an abnormality from the index produced by said third means; fifth means for determining a failure source from the index and the result obtained by said fourth means; and sixth means for outputting the abnormality and the failure source according to the results obtained by said fourth means and said fifth means

An apparatus according to the invention comprising:
a plant diagnostic system for a plant having a pluralities of variables, said diagnostic system including; means to estimate values of the plant variables using an auto regressive model of the plant to be diagnosed; means to calculate residuals, these being the differences between the actual values of the plant variables and the values estimated using the auto regressive model, means to calculate a correlation function on the basis of the residuals, means to diagnose, on the basis of the calculated correlation function, whether the plant is operating normally or not, is characterized in that the plant diagnostic system further

value is calculated and this value is fed back to the time series of difference calculation means 211.

The time series of difference calculation means 211 calculates the time series of difference ϵ_i (i represents an item number of the plant diagnostic model 20) i.e., a time series of difference between an estimated value and an actual value in respect of each plant value on the basis of the estimated value from the plant diagnostic model 20 and a value read from the object 19 to be diagnosed. After the deviation is calculated, the time series of difference calculation means 211 calculates an average per each item to calculate a residual by subtracting the average from respective deviations to output the time series of difference ϵ_i to the time series of difference whiteness qualification means 212.

The time constant determination means 213 inputs AR model coefficient matrices A(1), A(2), ..., A(M) of the AR model expressed by the equation (1) from the plant diagnostic model 20 to calculate an impulse response $I_i(\tau)$ given by the change of a plant value (the item number i) with respect to the change of a plant value (the item number j) in accordance with the following equations (6.1), (6.2), (6.3) and (6.4).

The time constant determination means 213 inputs AR model coefficient matrices A(1), A(2), ..., A(M) of the AR model expressed by the equation (1) from the plant diagnostic model 20 to calculate an impulse response $a_{ij}(\tau)$ given by the change of a certain plant value (item number i) with respect to the change of a certain plant value (item number j) to obtain sampling time which has the strongest influence on such a change.

For instance, the relationship expressed below holds in connection with the model of M=2 by the equation (1).

$$\mathbb{X}(s) = A(1)\,\mathbb{X}(s-1) + A(2)\,\mathbb{X}(s-2) \quad \cdots\cdots\cdots \quad (6.1)$$

To what degree the change of the plant value before one sample affects is calculated by the following equation.

$$\mathbb{X}(s) = A(1)\,\mathbb{X}(s-1) \quad \cdots\cdots\cdots\cdots\cdots \quad (6.2)$$

A value of the item number j in the $\mathbb{X}(s)$ when only a value of the item number i is set to 1 and values of other item numbers are set to 0 in the $\mathbb{X}(s-1)$ of the equation (6.2) is an impulse response given by the change of the plant value (item number i) before one sample with respect to the change of a certain value (the item number j).

For instance, when the model of M=2 is employed, i.e., the number of items is 2, the equation (6.1) is expressed as follows.

$$\begin{pmatrix} x_1(s) \\ x_2(s) \end{pmatrix} = \begin{pmatrix} A_{11}(1) & A_{12}(1) \\ A_{21}(1) & A_{22}(1) \end{pmatrix} \begin{pmatrix} x_1(s-1) \\ x_2(s-1) \end{pmatrix} + \begin{pmatrix} A_{11}(2) & A_{12}(2) \\ A_{21}(2) & A_{22}(2) \end{pmatrix} \begin{pmatrix} x_1(s-2) \\ x_2(s-2) \end{pmatrix} \quad \cdots\cdots\cdots\cdots \quad (6.1)$$

The impulse response given by the item number 2 before one sample to the item number 1 ($x_1(s)$) is calculated as follows.

(1) An impulse response $a_{12}(1)$ given by the item number 2 ($x_2(s-1)$) before one sample with respect to item number 1 ($x_1(s)$) is equal to a value of $x_2(s)$ in the equation (6.1) when $x_1(s-1) = 1$ and $x_2(s-1) = 0$ in the following equation:

$$\begin{pmatrix} x_1(s) \\ x_2(s) \end{pmatrix} = \begin{pmatrix} A_{11}(1) & A_{12}(1) \\ A_{21}(1) & A_{22}(1) \end{pmatrix} \begin{pmatrix} x_1(s-1) \\ x_2(s-1) \end{pmatrix}$$

given by the change in the plant value (the item number i) before τ samples with respect to each plant value (the item number j) is expressed as follows.

$$I_i(\tau) = \sum_{\ell=1}^{\tau-1} A(\ell)\ I_i(\tau-\ell) + \begin{pmatrix} A_{1i}(\tau) \\ A_{2i}(\tau) \\ \vdots \\ A_{ji}(\tau) \\ \vdots \\ A_{ni}(\tau) \end{pmatrix} \quad \ldots\ldots\ (6.5)$$

where i, j = 1,2,3, ..., n and τ = 1,2, ..., M, and when τ = 1,

$$I_i(\tau) = I_i(1) = \begin{pmatrix} A_{1i}(1) \\ A_{2i}(1) \\ \vdots \\ A_{ji}(1) \\ \vdots \\ A_{ni}(1) \end{pmatrix}$$

In addition, time constant τ_{ij} of the plant value (item number j) with respect to the plant value (item number i) is calculated on the basis of the following definition.

$\{\tau \| a_{ij}(\tau)| \geq |a_{ij}(\tau')|;\ \tau' \neq \tau, (\tau = 1,2,..,M), (\tau' = 1,2,..,M)\}$ ... (7)

Namely, τ_{ij} is defined as a value of τ which maximizes the absolute value of $a_{ij}(1)$, $a_{ij}(2)$, ..., $a_{ij}(\tau)$, ..., $a_{ij}(M)$.

It is considered that, when the plant value of the item number i varies, the time constant τ_{ij} thus obtained indicates a sampling time duration which has the greatest influence of such a change on the plant value of the item number j.

For example, it is assumed that a_{ij} calculated from the above equations (6.1) to (6.5) is evaluated as follows.

$a_{ij}(1) = -3.75$
$a_{ij}(2) = -4.71$
$a_{ij}(3) = 4.08$
$a_{ij}(4) = 6.10$
$a_{ij}(5) = 1.24$
$a_{ij}(6) = 5.02$
$a_{ij}(7) = 3.09$
$a_{ij}(8) = -2.89$

Because the absolute value of $a_{ij}(4)$ is the greatest, the time constant τ_{ij} is obtained as $\tau_{ij} = 4$.

The time constant τ_{ij} thus obtained is output from the time series of difference whiteness qualification means 212.

The time series of difference whiteness qualification means 212 receives the time series of difference ϵ_i output from the time series of difference calculation means 211 and the time constant τ_{ij} output from the time constant determination means 213 to calculate an index for qualifying whiteness of the time series of difference. For this, correlation function expressed by the following equation (8) is first calculated.

In the thermal power plant thus configured, the above-mentioned three manipulated variables are water-fuel ratio (item number 1) of fuel FR, reheater gas damper GD (item number 2) and super heater spray SP (item number 3), and the above-mentioned four state variables are addition demand value MWD (item number 4), SH outlet temperature MST (item number 5), RH outlet temperature RHT (item number 6) and main steam pressure MSP (item number 7).

When the above-mentioned plant variables are input to the plant diagnostic section 21, the time series of difference calculation means 211 outputs these plant variables to the plant diagnostic model 20 and takes therein estimated values of plant variables obtained based on calculation in the plant diagnostic model 20 in accordance with the previous outputs. Thus, the time series of difference calculation means 211 compares these estimated values with plant values which are input this time from the object 19 to be diagnosed to calculate time series of difference ϵ_i of each plant variable to output the time series of difference ϵ_i thus computed to the time series of difference whiteness qualification means 212.

In addition, the time constant determination means 213 inputs AR coefficient matrices A(1), A(2), ..., A-(M) from the plant diagnostic model 20 to calculate time constant τ_{ij} in accordance with the above-mentioned equations (6.5) and (7) to output the time constant τ_{ij} thus calculated to the whiteness qualification means 212.

The time series of difference whiteness qualification means 212 takes therein these time series of difference ϵ_i and time constant τ_{ij} to calculate whiteness qualification index AL_{ij} for judging relationship between items and abnormality or normarity to output the whiteness qualification index AL_{ij} thus calculated to the abnormality judgement means 215 and to the failure source determination means 216. At this time, by precluding in advance calculation such as whiteness qualification index AL_{63} from the state variable with respect to the manipulated variable etc. in connection with the abnormality which actually would not occur in the actual plant, for instance, "the abnormality of SH outlet temperature of the item number 5 has influence on SH spray of the item number 3", wasteful abnormality detection operation can be saved. Further, when seven plant values are grouped into manipulated variables and state variables and the whiteness qualification index AL_{ij} is calculated, e.g., by making use of the relationship determined so that i = 1 to 3 and j = 4 to 7, it is also possible to simply manipulated variables which causes the state variable to be abnormal.

When the plant is normal, the time series of difference ϵ_i takes random value which becomes non-correlated value. The whiteness qualification index AL_{ij} at this time depends upon the normal distribution (0, 1) (having average of 0 and dispersion of 1).

Thus, the threshold level for judging whether there is correlation or not can be determined from the table showing the normal distribution so that, for example, ARL = 1.96 at the erroneous diagnostic probability of 5% and ARL = 2.56 at the erroneous diagnostic probability of 1%. Namely, when $|AL_{ij}| \leq$ ARL, it is considered that the time series of difference has no correlation.

The abnormality judgement means 215 inputs AL_{ij} indicative of the auto-correlation function of the above-mentioned whiteness qualification index AL_{ij} to judge the item number i which satisfies the following relationship to be abnormal:

$$|AL_{ij}| > ARL.$$

The failure source determination means 216 inputs AL_{ij} ($i \neq j$) indicative of cross-correlation function of the above-mentioned whiteness qualification index AL_{ij} and the item number i judged to be abnormal by the abnormality judgement means 215 to judge the abnormality of the state variable (the item number j) to be based on the failure of the manipulated variable (the item number i) in connection with the manipulated variable (the item number i) and the state variable (the item number j) of which both item numbers i and j are abnormal.

It is now assumed that the whiteness qualification index AL_{ij} calculated by the whiteness qualification calculation means 212 is expressed by the following Table 1 and the threshold value of the erroneous diagnostic probability of 5% is set to ARL = 1.96.

APC 12 input and therefore they may be input from the APC 12.

(3) In the identification of the plant diagnostic model, the method was employed to vary at random load demand value which was a specified plant state variable thereby to derive mathematical model of the object 19 to be diagnosed. However, it is not required that the load demand value is necessarily used in any plant and it is of course that various plant state variables can be selected in accordance with the characteristic of the object 19 to be diagnosed.

(4) For identification of the plant diagnostic model, random signal such as M-series signal were used. In addition, it is possible to identify the plant diagnostic model with another random signal such as pseudo-random number.

(5) When not only the signal varying at random but also a step signal or ramp signal is applied to the state variable (the load demand value in the example shown in Fig. 3) which has the greatest influence on the object 19 to be diagnosed, a method may be employed to test in advance change of the whiteness qualification index AL_{ij} based on the plant diagnostic model 20, thereby to independently determine values of the threshold level ARL per each state variable.

(6) In the above-mentioned embodiment, the threshold level ARL was fixed. However, when disturbance which can be measured e.g., large change in load is applied to the object 19 to be diagnosed, for reducing the possibility of the erroneous diagnosis, it is possible to allow the threshold level ARL to be variable in accordance with the change in the disturbance which can be measured.

(7) When the diagnostic result is grasped on the basis of elevation of the abnormal level, it is possible to inform an operator of the approach to the alarm region for paying an attention to the operator and thus this can be utilized for preventing accident.

As described above, according to the present invention, while effecting the control of a plant, the diagnosis of the entirety of the plant including its control status can be carried out. In the implementation of the diagnosis, the characteristic of the entire plant is first obtained from the plant diagnostic model in terms of time constant, and then the diagnosis is actually conducted. Accordingly, this makes it possible to identify abnormality or failure source in conformity with the characteristic of the object to be diagnosed. In addition, since it is unnecessary to test the plant for obtaining the time constant, the plant can be effectively used as compared to other methods.

Claims

1. A plant diagnostic system wherein a plant to be diagnosed is expressed as an auto regressive model to calculate a correlation function on the basis of a difference between an estimated value of a plant variable calculated using said auto regressive model and the actual value of said plant variable, thus to diagnose said plant, **characterized by**
first means (213) for determining, using the coefficient matrix of the auto regressive model, a time constant at which a change in the value of one plant variable has the graetest influence on the value of the plant variable and other plant variables;
second means (211) for calculating a time series of residual differences between an estimated value calculated by using said plant diagnostic model and an actual plant value obtained from said plant system so as to obtain the time series of residual differences;
third means (212) for qualifying whiteness of the time series of residual differences from said second means and the time constant from said first means so as to produce an index;
fourth means (215) for determining an abnormality from the index produced by said third means;
fifth means (216) for determining a failure source from the index and the result obtained by said fourth means; and
sixth means (217) for outputting the abnormality and the failure source according to the results obtained by said fourth means and said fifth means.

2. A plant diagnostic system as set forth in claim 1, wherein said first means calculates impulse response $a_{ij}(\tau)$ indicating to what degree a change of a certain plant value (item number i) affects a change of another plant value (item number j) from said auto regressive model when auto regressive coefficient matrices
A(1), A(2), ..., A(M) expressed as

gegeben sind, um so die Zeitkonstante τ_{ij} zu berechnen, die den größten Einfluß hat.

3. Vorrichtung, umfassend:
ein Anlagen-Diagnosesystem (21) für eine Anlage mit einer Vielzahl von Variablen, wobei das Diagnosesystem folgendes beinhaltet;
Mittel zur Schätzung von Werten der Anlagenvariablen unter Verwendung eines autoregressiven Modells der zu diagnostizierenden Anlage;
Mittel (211) zur Berechnung von Resten, wobei diese die Differenzen zwischen den tatsächlichen Werten der Anlagenvariablen und den Werten, die unter Verwendung des autoregressiven Modells geschätzt wurden, sind;
Mittel (212) zur Berechnung einer Korrelationsfunktion auf der Basis der Reste;
Mittel (215) zur Diagnose auf der Basis der berechneten Korrelationsfunktion, ob die Anlage normal läuft oder nicht,
dadurch gekennzeichnet, daß das Anlagen-Diagnosesystem (21) ferner ein Zeitkonstanten-Bestimmungsmittel (213) enthält, das die Koeffizientenmatrix des autoregressiven Modells zur Berechnung einer Zeitkonstante verwendet, zu welcher eine Veränderung des Wertes einer Anlagenvariablen den größten Einfluß auf den Wert der Anlagenvariablen und die anderen Anlagenvariablen hat, und
das Mittel (212) zur Berechnung einer Korrelationsfunktion den berechneten Wert der Zeitkonstante wie auch die Werte der Reste verwendet.

Revendications

1. Système de surveillance d'installation dans lequel une installation à surveiller est exprimée selon un modèle auto régressif pour calculer une fonction de corrélation sur la base de la différence entre une valeur estimée d'une variable d'installation calculée en utilisant ledit modèle auto régressif et la valeur réelle de ladite variable d'installation, effectuant ainsi la surveillance de ladite installation, caractérisé par
un premier moyen (213) pour déterminer, en utilisant la matrice des coefficients du modèle auto régressif, une constante de temps pour laquelle une modification de la valeur d'une variable d'installation possède l'influence la plus importante sur la valeur de la variable d'installation et des autres variables d'installation;
un second moyen (211) pour calculer une série temporelle de différences résiduelles entre une valeur estimée calculée en utilisant ledit modèle de surveillance d'installation et une valeur réelle d'installation obtenue à partir dudit système d'installation de façon à obtenir une série temporelle des différences résiduelles;
un troisième moyen (212) pour qualifier la blancheur de la série temporelle des différences résiduelles à partir dudit second moyen et la constante de temps à partir dudit premier moyen afin de produire un indice;
un quatrième moyen (215) pour déterminer une anomalie à partir de l'indice produit par ledit troisième moyen;
un cinquième moyen (216) pour déterminer une source de défaillance à partir de l'indice et du résultat obtenu par ledit quatrième moyen; et
un sixième moyen (217) pour délivrer en sortie l'anomalie et la source de défaut selon les résultats obtenus par ledit quatrième moyen et par ledit cinquième moyen.

2. Système de surveillance d'installation selon la revendication 1, dans lequel ledit premier moyen calcule la réponse impulsionnelle $a_{ij}(\tau)$, indiquant dans quelle mesure la modification d'une certaine valeur d'installation (élément numéro i) modifie une autre valeur d'installation (élément numéro j) d'après ledit modèle auto régressif lorsque les matrices des coefficients auto régressifs
A(1), A(2), ..., A(M) exprimés par

$$\widehat{X}(s) = \sum_{m=1}^{M} A(m)\cdot X(s-m)$$

sont données pour calculer ainsi ladite constante de temps τ_{ij} qui possède l'influence la plus

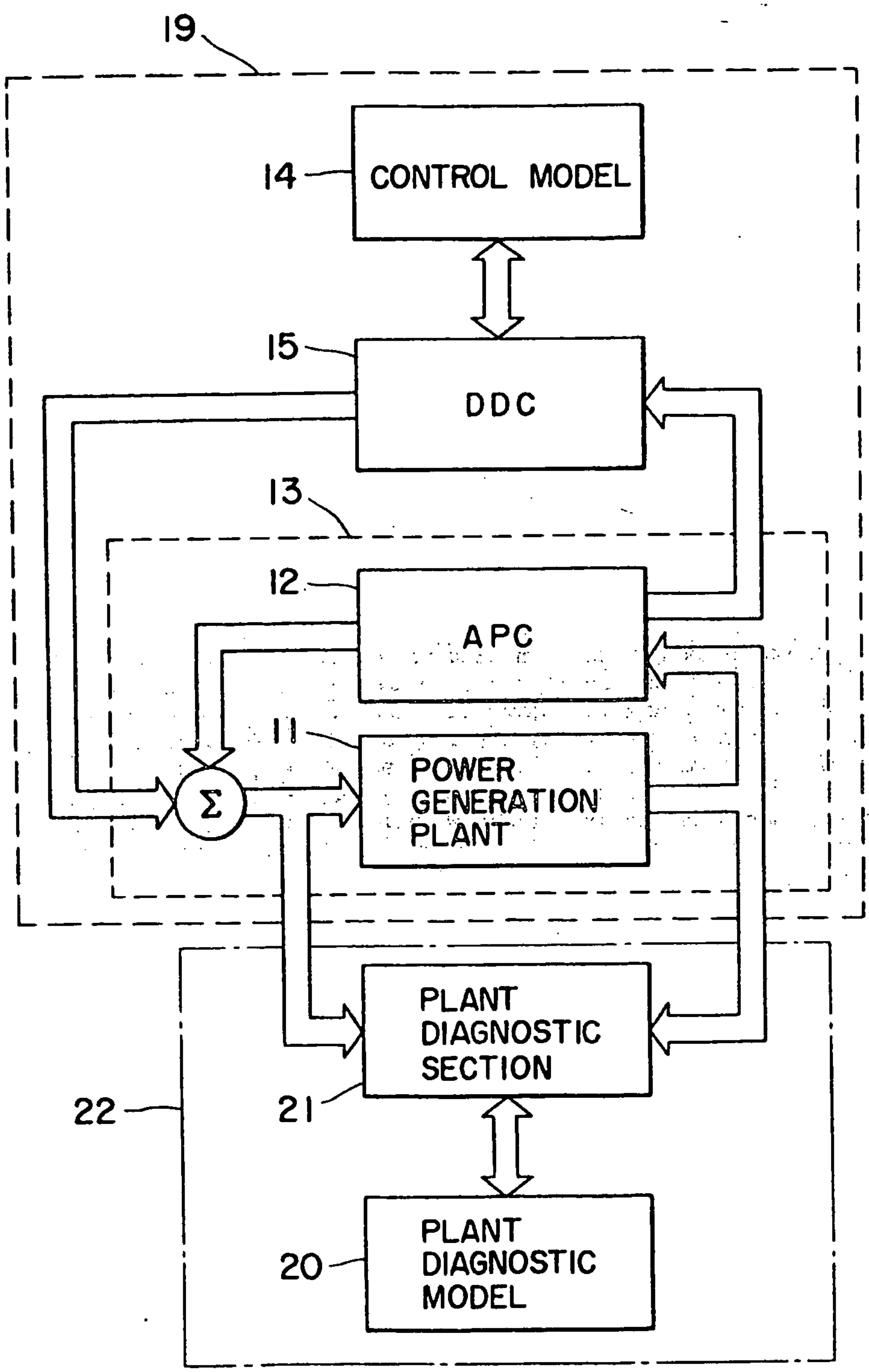
19
14
CONTROL MODEL
15
DDC
13
12
APC
11
POWER GENERATION PLANT
Σ
PLANT DIAGNOSTIC SECTION
22
21
PLANT DIAGNOSTIC MODEL
20

FIG. 1

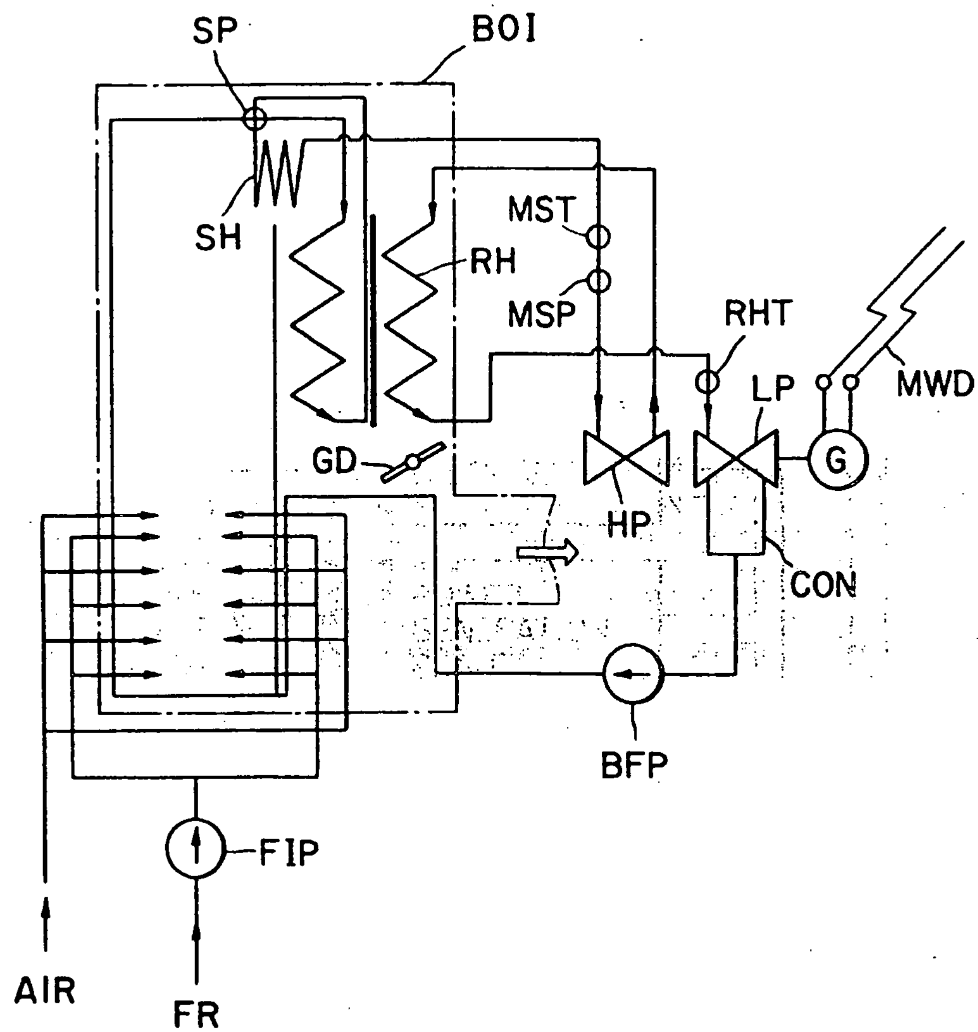

FIG. 3